METHODS OF SUPPRESSING RINGING ARTIFACT OF DECOMPRESSED IMAGES

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Field of the Invention

The present invention relates generally to video processing, and more particularly to video image compression.

Background of the Invention

The development of modern digital video technology has enhanced the video quality for consumer electronics such as in DVD players and digital TV (DTV) systems, as compared to analog TV systems. However, significant video enhancement shortcomings remain in digital video systems such as DTV systems, including contrast enhancement, brightness enhancement and detail enhancement.

Post processing for decompressed pictures plays an important role in the quality of any digital video system depending on compression technology. This is because artifacts inherently arise as a result of data quantization in data compression. Examples include blocking artifacts, ringing artifacts, mosquito noise, etc. When a digital image or video has been compressed to a low bit rate, such artifacts are

especially annoying.

Conventionally, a low-pass-filter has been used to remove the ringing artifacts from the digital picture. However, the low-pass-filter also removes the picture details which

5   introduces blurring artifacts. There is, therefore, a need for a method of suppressing ringing artifacts that commonly arise in decompressed pictures.

Brief Summary of the Invention

The present invention addresses the above shortcomings.

10   In one embodiment, the present invention provides a systematic way of detecting ringing-like areas in a picture by examining local statistics. This allows adaptive suppression of ringing artifacts without introducing blurring to the areas where no ringing artifacts are detected.

15   A suppression method that provides adaptive (i.e., selective) processing of an input picture to generate an enhanced output picture with ringing-like areas of the input picture suppressed. Subsets of the input picture are analyzed as one or more windows. For each such window in the input

20   picture, if the window is around a ringing-like area in the picture, then the output picture comprises the low-pass filtered (i.e., smoothed) window in the input picture. However, if the window is not around a ringing-like area

(i.e., the window is around a non-ringing-like area) then the output picture comprises essentially the unchanged window in the input picture. As a result no blurring is introduced into the input picture in areas where ringing-like patterns are not

5   detected. Therefore, the output picture includes portions of the input picture in which ringing-like patterns were not detected, and portions of the input picture with suppressed ringing-like patterns where detected. The output picture is an enhanced version of the input picture with suppressed

10   (i.e., smoothed) ringing-like patterns.

In another embodiment, the present invention further provides a device that adaptively reduces ringing artifacts in an input image including pixels of image information. In one

15   example, such a device reduces ringing artifacts comprises: a ringing-artifact detector that detects areas of ringing artifacts in a pixel window based on the pixel information, the pixel window including a set of pixels from the input image pixels; an image processor that processes window pixels

20   to generate pixels with reduced ringing artifacts; and a combiner that selects the processed pixels with reduced ringing artifacts in the detected ringing-artifact areas, and generates an output image comprising: (i) the selected

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processed pixels with reduced ringing artifacts, and (ii) the remaining window pixels.

Brief Description of the Drawings

5   These and other features, aspects and advantages of the present invention will become understood with reference to the following description, appended claims and accompanying figures where:

FIG. 1 shows an example window in a digital picture that
10   is processed using an embodiment of an adaptive suppression method according to the present invention;

FIG. 2 shows a flowchart of the steps of an embodiment of an adaptive suppression method according to the present invention;

15   FIG. 3 shows an example curve representing an example relationship between local variances $\sigma(y,x)$ in a signal detection function $\beta(y,x)$; and

FIG. 4 shows a block diagram of an example architecture of an adaptive suppression device according to the present
20   invention.

Detailed Description of the Invention

Overview

As noted above, in one embodiment, the present invention

5   provides a method of detecting ringing-like areas in a picture

by examining local statistics in the picture. This allows

adaptive reduction (e.g., suppression) of ringing artifacts in

decompressed pictures, without introducing blurring to the

areas where no ringing artifacts are present, according to the

10   present invention. Referring to **FIG. 1**, in one example, the

set $\{I\}$ denotes a decompressed picture (field or frame) 10, and

$I(y,x)$ denotes a gradation value of the xth pixel 12 of the yth

line of the picture 10.

FIG. 2 shows a flowchart of the steps of an example

15   suppression method according to the present invention. The

suppression method includes the steps of:

Computing local variance/deviation $\sigma(y,x)$ for each

pixel 12 in the image 10 based on neighboring pixels in the

NXM window 14 (step 20);

20   Using the local variances $\sigma(y,x)$ in a signal

detection function $\beta(y,x)$ to detect if the window 14 is in a

noisy area (small local deviation) or in a good signal area

(large local deviation), in the input picture 10 (step 22);

Detecting ringing-like patterns in the window 14

using a ringing-like pattern detection function $g(y,x)$ (step

24);

Using detection of noisy/signal area and detection

5   of ringing-like-patterns in a ringing-like pattern area

function $\gamma(y,x)$ to determine if the window 14 is around

ringing-like pattern area in the picture 10 (step 26)

Performing low pass filtering on a copy of the input

picture 10 (step 28); and

10   Selectively combining portions of $\{I\}$ with portions

of $I_{LPF}(y,x)$ based on detected ringing-like pattern areas, to

generate enhanced signal J (y, x) where ringing-like areas are

essentially suppressed (step 30).

Such a method provides adaptive (i.e., selective)

15   processing of the input picture 10 to generate an enhanced

output picture with ringing-like areas of the input picture 10

suppressed. As such, in the above example, for each input

pixel $I_n(y,x)$. Based on such NxM neighbor pixel window 14, if

the window 14 is around a ringing-like area in the picture 10,

20   then the output pixel J (y, x) comprises the low-pass filtered

(i.e., smoothed) pixel of the input picture. However, if the

window 14 is not around a ringing-like area (i.e., the window

is around a non-ringing-like area) then the output pixel

J (y, x) comprises essentially the unchanged pixel of the input picture which is *J (y, x)*. As a result no blurring (due to smoothing) is introduced into the input picture in areas where ringing-like patterns are not detected. Therefore, the

5   output picture comprises portions of the input picture in which ringing-like patterns were not detected, and portions of the input picture with low pass filtering where ringing-like patterns were detected. Note that this changes from pixel to pixel. The output picture is an enhanced version of the input

10 picture with suppressed (i.e., smoothed) ringing-like patterns.

Example Implementation

In one example implementation described

15 hereinbelow, $I_{LPF}(y,x)$ denotes the gradation value of the xth pixel of the yth line of the picture $\{I\}$ after low-pass-filtering. A local deviation $\sigma(y,x)$ for $I(y,x)$ in the picture $\{I\}$ is computed based on the local/neighboring samples (pixels) of $I(y,x)$. This can be performed using a window centered at (y,x) and

20 computing the variance of the samples in the window. Although any arbitrary window shape can be used, an $N \times M$ rectangular window is used in the description herein for explanation purposes.

The deviation value $\sigma(y,x)$ can be computed as:

$$\sigma(y,x) = \sqrt{\frac{\sum_{i=1}^{N}\sum_{j=1}^{M}(w_{i,j} - m(y,x))^2}{N \cdot M}} \qquad (1)$$

where $w_{i,j}$ is the $(i,j)^{th}$ element of the $N \times M$ rectangular window, and $m(y,x)$ is the mean of the samples in the $N \times M$ rectangular window, wherein:

$$m(y,x) = \frac{\sum_{i=1}^{N}\sum_{j=1}^{M} w_{i,j}}{N \cdot M} \ .$$

Because the expression in relation (1) can be expensive to compute, alternatively the following relation can be used to determine the local deviation, wherein:

$$\sigma(y,x) = \frac{\sum_{i=1}^{N}\sum_{j=1}^{M}|\, w_{i,j} - m(y,x)\,|}{N \cdot M} \ . \qquad (2)$$

Further, the denominator $N \cdot M$ in relation (2) is a constant, once the dimensions of the window have been determined. As such, the following relation can be used to determine a relative quantity of the local deviation as:

$$\sigma(y,x) = \sum_{i=1}^{N}\sum_{j=1}^{M}|\, w_{i,j} - m(y,x)\,| \ . \qquad (3)$$

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A computation according to relation (3) is simpler in terms of a hardware implementation than (1) or (2).

Detecting Noisy and Good-Signal Image Areas

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Based on the local deviation $\sigma(y,x)$, a signal detection function $\beta(y,x)$ based on $\sigma(y,x)$ is selected, wherein the signal detection function $\beta(y,x)$ satisfies the following three constraints:

10   As $\sigma(y,x)$ increases, $\beta(y,x)$ approaches 1,

As $\sigma(y,x)$ decreases to 0, $\beta(y,x)$ approaches 0, and

$\beta(y,x)$ monotonically increases as $\sigma(y,x)$ increases.

Other signal detection functions which satisfy the above three constraints can also be utilized.

15   As described further below, the role of the signal detection function $\beta(y,x)$ is to detect whether the widow is located in a noisy area (i.e., small local deviation),in a signal area (i.e., large local deviation) or between. In this example, the value of $\beta(y,x)$ is bounded as $0 \leq \beta(y,x) \leq 1$. In

20 general, when $\beta(y,x)$ is close to zero, it implies the window is substantially in a noisy area, and when $\beta(y,x)$ is close to one,

it implies that the window is substantially in a signal area (for simplicity, it is assumed that the noise level is smaller than the signal level).

One example of the signal detection signal $\beta(y,x)$ can be:

$$\beta(y,x) = \begin{cases} 0, & \sigma(y,x) \leq t_1 \\ \dfrac{\sigma(y,x)-t_1}{t_2-t_1} & t_1 \leq \sigma(y,x) \leq t_2 \\ 1, & \sigma(y,x) \geq t_2 \end{cases} \qquad (5)$$

wherein t_1 and t_2 are some pre-determined constants. As shown by the example curve 31 in **FIG. 3**, depending on the values of t_1 and t_2, the characteristics of $\beta(y,x)$ can be defined in association with the value of $\sigma(y,x)$. The ranges for t_1 and t_2 are dependent on application.

Detecting Ringing-Like Patterns

In detecting a ringing-like pattern in the window, in one example, a ringing like area is recognized as a weak (small) edge area. The weak edge area is indicated by a gradation level difference between a pixel and its neighboring pixels, that is within a selected threshold. In one example, a relatively small gradation level difference indicates that there might be weak (small) edge at the pixel position. A large gradation level difference implies that

there might be a strong edge at the pixel position. In real

images, ringing does not exhibit a strong edge. Therefore,

to detect a ringing-like pattern in the window, a pattern

detection function $g(y,x)$ is utilized, wherein $g(y,x)$ includes the

5   components g_x *(y, x)* and g_y *(y, x)*, such that:

$$g_x(y,x) = \frac{\Delta_x^{\min}}{\Delta_x^{\max}} \qquad (6)$$

where:

$$\Delta_x^{\max} = \max(|I(y,x-1)-I(y,x)|,|I(y,x+1)-I(y,x)|)$$

$$\Delta_x^{\min} = \min(|I(y,x-1)-I(y,x)|,|I(y,x+1)-I(y,x)|) \,,$$

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and

$$g_y(y,x) = \frac{\Delta_y^{\min}}{\Delta_y^{\max}} \qquad (7)$$

where:

$$\Delta_y^{\max} = \max(|I(y+1,x)-I(y,x)|,|I(y-1,x)-I(y,x)|)$$

15   $$\Delta_y^{\min} = \min(|I(y+1,x)-I(y,x)|,|I(y-1,x)-I(y,x)|) \,.$$

The component g_x *(y, x)* indicates ringing pattern-like

features in the horizontal direction in the window and the

component g_y *(y, x)* indicates ringing pattern-like features in

the vertical direction in the window. As such, the ringing-

20   like pattern detection function $g(y,x)$ can be represented as:

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$$g(y,x) = \max(g_x(y,x), g_y(y,x)) \qquad (8)$$

where $0 \le g(y,x) \le 1$.

For a given pixel I (y, x) the larger the gradation level difference between that pixel and its neighboring pixels, then the lower the ringing effect (i.e., $g(y,x)$ decreases). When $g(y,x)$ is close to zero, it implies a substantially non-ringing-like pattern, and when $g(y,x)$ is close to one, it implies a substantially ringing-like pattern.

Detecting Ringing-Like Areas

A combination of the signal detection function $\beta(y,x)$ and the ringing-like pattern detection function $g(y,x)$, provides a ringing-like area detection function $\gamma(y,x)$ which satisfies the constraints in Table 1 below:

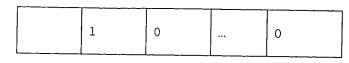| $\gamma(y,x)$		$g(y,x)$		
		0	$\rightarrow$	1
$\beta(y,x)$	0	0	...	1
	$\downarrow$	$\vdots$	$\ddots$	$\vdots$

	1	0	...	0

Table 1

The arrows in Table 1 indicate a corresponding value changing from e.g., 0 to 1.

One example of the function $\gamma(y,x)$ satisfying said constraints can be:

$$\gamma(y,x) = (1 - \beta(y,x)) \cdot g(y,x) . \qquad (9)$$

In one example, when $\gamma(y,x) = 1$, it implies that the window is located around a ringing-like pattern area, whereas when $\gamma(y,x) = 0$, it implies that the window is located around a non-ringing-like pattern area.

Generating Enhanced Output Image

Based on the ringing-like area detection function $\gamma(y,x)$, an enhanced output J (y, x) is provided as:

$$J(y,x) = (1 - \gamma(y,x)) \cdot I(y,x) + \gamma(y,x) \cdot I_{LPF}(y,x) \qquad (10)$$

wherein J (y, x) combines the original sample values I (y, x) and the low-pass-filtered values I_{LPF} (y, x) depending on the degree of ringing-like value $\gamma(y,x)$.

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If a ringing-like area is detected (e.g., $\gamma(y,x)=1$), then:

$$J(y,x) = I_{LPF}(y,x)$$

which implies a smoothed output.

If a non-ringing-like area is detected (e.g., $\gamma(y,x)=0$),

5   then:

$$J(y,x) = I(y,x)$$

which implies that no change is made and thus no blurring

is introduced.

Relation (10) above represents a point-to-point process,

10   wherein the value of $\gamma(y,x)$ is estimated point-to-point (or,

pixel-to-pixel).   Hence, relation (10) provides an adaptive

de-ringing method according to an embodiment of the present

invention.

15   Although in the preferred embodiment described above,

both the signal detection function $\beta(y,x)$ and the pattern-like

detection function $g(y,x)$, are used in relations (9) and (10)

above, in other embodiments of the present invention, the

pattern-like detection function $g(y,x)$ can be used independent

20   of the signal detection function $\beta(y,x)$.   As such, in an

alternative example, relation (10) above for generating the output picture $J(y, x)$ can modified to be:

$$J(y,x) = (1 - g(y,x)) \cdot I(y,x) + g(y,x) \cdot I_{LPF}(y,x) \qquad (10a)$$

5   Adaptive Suppression Device

FIG. 4 shows a block diagram of an example architecture of an embodiment of an adaptive suppression device 40 according to the present invention, implementing the above

10   method. The device 40 includes: a low-pass filter (LPF) block 42; a local variance compute block 44 that computes the local deviation $\sigma(y,x)$ for a pixel in a window based on neighboring pixels; signal detection function block 46 that uses the local variances $\sigma(y,x)$ to detect location of the window in relation

15   to noisy and signal areas in the input picture; a ringing-like detection function block 48 that detects ringing-like patterns using the function $\beta(y,x)$; a ringing-like area detection block 50 that uses detection of noisy/signal area and detection of ringing-like-patterns in the ringing-like pattern area

20   function $\gamma(y,x)$ to determine if window is around ringing-like pattern area in the picture; and a combiner that selectively combines portions of $\{I\}$ with portions of $I_{LPF}(y,x)$ based on detected ringing-like pattern areas (as described), to

generate enhanced output signal $J\ (y,\ x)$ representing an output picture in which ringing-like areas are essentially suppressed .

5   The example suppression device in FIG. 4 can be implemented in many ways known to those skilled in the art, such as for example, as program instructions for execution by a processor, as logic circuits such as ASIC, etc. For example, instead of low pass filtering, other methods of

10 suppressing ringing like artifacts in the input picture can be used according to the present invention. Further, other methods for detecting other artifacts, and suppression of such artifacts can also be utilized according to the present invention. As such, while this invention is susceptible of

15 embodiments in many different forms, there are shown in the drawings and described herein, preferred embodiments of the invention with the understanding that the present disclosure is to be considered as an exemplification of the principles of the invention and is not intended to limit the broad aspects

20 of the invention to the embodiments illustrated. Therefore, the spirit and scope of the appended claims should not be limited to the description of the preferred versions contained herein.